The Effect of a Magnetic Field on the Electrical Conductivity of Flame.

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The following paper contains an account of some measurements of the change in the conductivity of a Bunsen flame produced by a magnetic field the direction of which was perpendicular to the current through the flame and to the motion of the flame gases. The velocity of the negative ions in the flame has been calculated from the results, and the value of the velocity obtained agrees approximately with that found by other methods.

The flame used consisted of a row of 12 small Bunsen flames burning from quartz tubes. The centres of the tubes were 1 cm. apart, and each tube had an internal diameter of 0·5 cm. Each flame was about 6 cm. high, and the adjacent flames touched each other, so that a flame about 14 cm. long, 6 cm. high, and about 2 cm. thick was obtained.

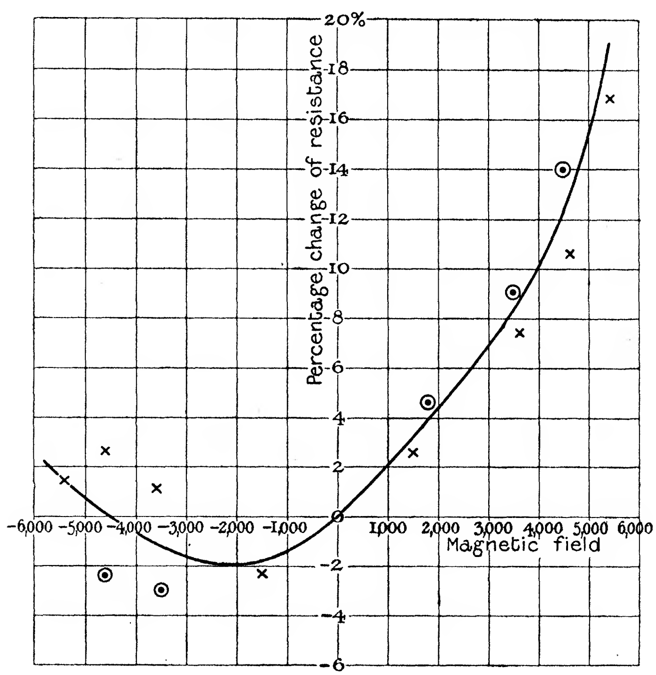
Two platinum disk electrodes were supported in the flame facing each other about 10 cm. apart, and were connected through a galvanometer to a battery of secondary cells. Some potassium carbonate was put on the negative electrode to increase the current.

The potential gradient along the flame was measured by means of two platinum wires which were supported horizontally in the flame perpendicular to the horizontal line joining the centres of the disk electrodes. These wires were connected to an electrostatic multicellular voltmeter. The capacity of the voltmeter was increased by connecting it to a $\frac{1}{3}$ microfarad condenser, and large amyl-alcohol resistances were put in the wires leading from the flame to the voltmeter. This arrangement was adopted to prevent the small oscillations of the flame making the voltmeter needle unsteady. The flame was placed between the poles of a large Du Bois electromagnet, the conical pole pieces of which had been removed so that a fairly uniform field could be produced in a horizontal direction perpendicular to the line joining the disk electrodes.

It was found that passing a current through the magnet produced a gradual change in the conductivity of the flame, which remained when the current was stopped. This appeared to be due to the heating of the coils altering the draught of air to the flame. In addition to this effect there was a sudden change in the conductivity on turning the magnetic field on or off. It was easy to disentangle the two effects, but only rather rough measurements could be obtained.

The ratio of the potential difference between the two wires to the current was taken as a measure of the resistance of the flame. It has been shown by several observers that this ratio is independent of the current.

It was found that the percentage change in the resistance for a given magnetic field did not vary much with the current. Two sets of observations, one with potential differences between the platinum wires of from 200 to 400 volts and the other with from 50 to 150 volts, gave nearly equal results. The distance between the platinum wires was 7 cm. The results obtained are shown in the figure, the percentage change of resistance being plotted against the strength of the magnetic field. Each point represents the mean of several observations. The crosses are the results obtained with the higher potentials and the circles those obtained with the lower. It will be seen that with the field in one direction the resistance was increased by an amount increasing more rapidly than the field, whereas with the field in the opposite direction the resistance was diminished with small fields, but slightly increased with fields above about 4000.



Owing to the upward motion of the flame gases there is an induced electric force along the flame which opposes the current when the field is on in one direction and helps it with the field in the other direction. If

therefore, we take the mean of the effects for the two directions of the magnetic field, we shall get the value of the effect which would have been obtained with the flame gases at rest.

The following table contains the values obtained in this way, using values taken off the curve :—

Magnetic field (H).	Percentage change of resistance (σ).	σ/H^2.
1000	0·3	$3 \cdot 0 \times 10^{-7}$
2000	1·3	$3 \cdot 2 \times 10^{-7}$
3000	2·6	$2 \cdot 9 \times 10^{-7}$
4000	4·8	$3 \cdot 0 \times 10^{-7}$
5000	8·0	$3 \cdot 2 \times 10^{-7}$
	Mean............	$3 \cdot 1 \times 10^{-7}$

The last column contains the values of σ/H^2, which do not differ much.

If it is assumed that the velocity of the positive ions in the flame is small compared with the velocity of the negative ions, then we may apply Sir J. J. Thomson's* theory of the effect of a magnetic field on the conductivity of metals to the flame. According to the theory we have $\sigma/100 = \frac{1}{3} H^2 k^2$ where k denotes the velocity of the negative ions due to one electromagnetic unit of electric force. Hence $k = (3\,\sigma/100\,H^2)^{\frac{1}{2}} = 9 \cdot 6 \times 10^{-5}$ cm./sec. For 1 volt per centimetre this gives $k = 9600$ cm./sec.

Mr. E. Gold† measured the velocity of the negative ions in a Bunsen flame and found $k = 8000$ by one method and 13,000 by another. The result just obtained is nearly equal to the mean of his two results. The velocity, of course, must vary to some extent in different Bunsen flames.

Half the difference between the effects with the magnetic field in the two directions gives the effect presumably due to the induced electric force in the flame. The following table contains the values of this effect:—

Magnetic field (H).	Percentage change of resistance (δ).	δ/H.
1000	1·7	$1 \cdot 7 \times 10^{-3}$
2000	3·1	$1 \cdot 6 \times 10^{-3}$
3000	4·3	$1 \cdot 4 \times 10^{-3}$
4000	5·4	$1 \cdot 4 \times 10^{-3}$
5000	7·4	$1 \cdot 5 \times 10^{-3}$

* 'Rapports Congrès International de Physique,' Paris, 1900, vol. 3, p. 144.
† 'Roy. Soc. Proc.,' A, vol. 79, 1907.

The last column shows that the effect is approximately proportional to the magnetic field, as was to be expected. If v denotes the velocity of the flame gases, we should expect the induced electric force to be equal to Hv, and hence $\delta/100 = vH/X$, where X denotes the strength of the electric force along the flame.

This was not less than 10 volts per centimetre, so that we get $v = X\delta/100H > 10^4$ cm./sec.

Now the velocity of the gases in a Bunsen flame is not more than 200 cm./sec., so that it appears that this effect is at least 50 times greater than was to be expected. In fact, if it had had the value to be expected it would have been negligible, and the change of resistance would have been independent of the direction of the magnetic field.

It appears, therefore, that the effect of the magnetic field on the resistance of the flame can be represented as the sum of two terms, one proportional to the square of the field and the other proportional to the field. The first term has the value to be expected, but the other term is much too large.

The discrepancy would be removed if the negative ions moved *upwards* with a velocity proportional to the horizontal electric field and equal to 10^4 cm./sec. for 10 volts per centimetre, but there does not seem to be any reason for supposing that they do so. If the two wires in the flame are connected to a quadrant electrometer the induced electric force in the flame, when no current is flowing, due to the upward motion of the flame gases in the magnetic field, can easily be measured, and it is approximately equal to the product of H and the velocity. If $H = 5000$ and $v = 200$ the induced force is 0·01 volt per centimetre, whereas to explain the observed change in the resistance it would have to be 0·5 volt per centimetre for a field along the flame of 10 volts per centimetre.

I am not at present able to offer a satisfactory explanation of the magnitude of the part of the effect proportional to the field.

In conclusion, I wish to say that my thanks are due to Mr. G. H. Martyn, B.Sc., for his assistance in carrying out the experiments described.